2011 International Workshop on EUV Lithography

June 13-17, 2011

Makena Beach Golf Resort ▪ Maui, Hawaii

Workshop Abstracts

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Contents

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Welcome

Dear Colleagues;

I would like to welcome you to the 2011 International Workshop on EUV Lithography in Maui, Hawaii. In this leading workshop, focused entirely on EUVL R&D, researchers from around the world will present the results of their R&D. As we all work to address the remaining technical challenges of EUVL to allow its insertion in high volume computer chip manufacturing, we look forward to a productive interaction among colleagues to brainstorm technical solutions.

This workshop has been made possible by the support of workshop sponsors, steering committee members, workshop support staff, session chairs and presenters. I would like to thank them for their contributions and making this workshop a success. I look forward to your participation.

Best Regards

Vivek Bakshi
Organizing Chair, 2011 International Workshop on EUVL

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Workshop Agenda

2011 International Workshop on EUV Lithography

Makena Beach Golf Resort, Maui, Hawaii, USA
June 13-17, 2011

Workshop Agenda Outline

Short Courses (Makena Room, June 13, 2011)

EUV Lithography
8:00 AM -5:00 PM, Monday, June 13, 2011

EUVL Workshop (June 14-17, 2011)

Tuesday, June 14, 2011

3:00 PM- 5:00 PM	Registration (Kaeo Ballroom Entry Lanai) Speaker Prep (Wailea Room)
5:00 PM- 7:00 PM	Reception (Pacific Lawn)

Wednesday, June 15, 2011

7:00 AM	–	8:00 AM	Breakfast
8:30 AM	–	12:00 PM	Oral Presentations (Wailea Room)
12:00 PM	–	1:00 PM	Lunch (Holokai Pavilion)
1:00 PM	–	4:00 PM	Oral Presentations (Wailea Room)
4:00 PM			Afternoon off for Networking /Sunset Cruise

Thursday, June 16, 2011

7:00 AM	–	8:00 AM	Breakfast
9:00 AM	–	12:00 PM	Oral Presentations (Wailea Room)
12:00 PM	–	1:00 PM	Lunch (Holokai Pavilion)
1:00 PM	–	4:00 PM	Oral Presentations (Wailea Room)
5:00 PM	-	6:00 PM	Poster Session
6:00 PM			Dinner (Pacific Lawn)

Friday, June 17, 2011

8:30 AM	–	10:00 AM	EUVL Workshop Steering Committee Meeting (Kaeo Ballroom)

2011 International Workshop on EUV Lithography

Makena Beach Golf Resort, Maui, Hawaii, USA
June 13-17, 2011

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Short Courses

EUV Lithography
by Vivek Bakshi (EUV Litho, Inc.), Patrick Naulleau (LBNL) and Jinho Ahn (Hanyang University)
8:00 AM -5:00 PM, Monday, June 13, 2011

Tuesday, June 14, 2011

Registration and Reception

3:00 PM- 5:00 PM	Registration & Speaker Prep
5:00 PM- 7:00 PM	Reception

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Wednesday, June 15, 2011

8:30 AM Welcome and Introduction

Vivek Bakshi
EUV Litho, Inc., Austin, TX, USA

Session 1: Keynote Presentations

EUV Lithography and EUVL Sources: From the Beginning to NXE and Beyond (P1)
Vadim Banine
ASML, Eindhoven, Netherlands

Development and Optimization of EUV Emission from Laser Produced Plasmas (P2)
Gerry O'Sullivan
University College Dublin, Dublin, Ireland

Break

Doing Business in Maui (P39)
Kimberly Haueisen, Mark Ausbeck*
Maui Economic Development Board (MEDB), Inc., Kihei, Hawaii, USA
*** High Tech Development Corporation (HTDC), Kihei, Hawaii, USA***

Session 2: Patterning

EUV Interference Lithography for 1X nm (P8)
Takeo Watanabe, Yuya Yamaguchi, Takuro Urayama, Naohiro Matsuda,
Tetsu Harada and Hiroo Kinosita
Center for EUVL, Laboratory of Advanced Science and Technology for Industry, University of Hyogo, Hyogo, Japan

EUV Lithography Simulation for the 16 nm Node (P17)
Eun-Jin Kim, GukJin Kim, Seong-Sue Kim*, Han-Ku Cho*, Jinho Ahn**, Ilsin An, and Hye-Keun Oh
Lithography Lab., Department of Applied Physics, Hanyang University, Ansan, S. Korea
**Samsung Electronics Co., LTD., Hwasung-City, Gyeonggi-Do, Korea*
***Department of Material Science and Engineering, Hanyang University, Seoul, S. Korea*

LER Metrology: Can We Trust the Numbers? (P31) (Invited Paper)
Patrick Naulleau
Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Lunch (Holokai Pavilion)

Session 3: EUV Source Modeling

Radiative Hydrodynamic Simulation of Laser-produced Tin Plasma for Extreme Ultraviolet Lithography (P10)
Atsushi Sunahara[1], Katsunobu Nishihara [2], A. Sasaki [3], and Tsukasa Hori [4]
[1] *Institute for Laser Technology, 2-6 Yamadaoka Suita Osaka 565-0871*
[2] *Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka Suita Osaka 565-0871*
[3] *Quantum Beam Science Directorate, Japan Atomic Energy Agency, 8-1 Umemidai, Kizugawa Kyto 619-0215 Japan*
[4] *EUVA*

Progress in Modelling of High Intensity Radiation Plasma Sources (P26)
S.V. Zakharov[ab+], V.S. Zakharov[a], P. Choi[ab], G. O'Sullivan[d], A.Y. Krukovskiy[c], V.G. Novikov[c], A.D. Solomyannaya[c], A.V. Berezin[c], A.S. Vorontsov[c], M.B. Markov[c], S.V. Parot'kin[c]
[a] *EPPRA sas, Villebon/Yvette, France*
[b] *NANO-UV sas, Villebon/Yvette, France*
[c] *Keldysh Institute of Applied Mathematics RAS, Moscow, Russia*
[d] *University College Dublin (UCD), Ireland*
[+] *also with NRC Kurchatov Institute, Moscow, Russia*

Session 4: Next Generation EUV Sources

Rare-Earth Plasma EUV Source at 6.7 nm for Future Lithography (P5) (Invited Paper)
Takeshi Higashiguchi[1,2], Takamitsu Otsuka[1], Noboru Yugami[1,2], Deirdre Kilbane[3], Thomas Cummins[3], Colm O'Gorman[3], Tony Donnelly[3], Padraig Dunne[3], and Gerry O'Sullivan[3], Weihua Jiang[4], and Akira Endo[5]
[1]Department of Advanced Interdisciplinary Sciences, and Center for Optical Research & Education (CORE) Utsunomiya University, Utsunomiya, Tochigi, Japan
[2]Japan Science and Technology Agency, CREST, Kanagawa, Saitama 332-0012, Japan
[3]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland
[4]Department of Electrical Engineering, Nagaoka University of Technology , Nagaoka, Niigat, Japan
[5]Waseda University, Research Institute for Science and Engineering, Waseda University , Shinjuku, Tokyo, Japan

Atomic and Radiative Processes in Plasmas for the Shorter Wavelength Extreme ultra-violet (EUV) Light Sources (P7)
Akira Sasaki
Quantum Beam Science Directorate, Japan Atomic Energy Agency, Kizugawa-shi, Kyoto, Japan

Design of High Brightness Laser-Compton Light Source for EUV Lithography Research in Shorter Wavelength Region (P30) (Invited Paper)
Kazuyuki Sakaue, Masakazu Washio, Akira Endo
Research Institute of Science and Engineering, Waseda University, Shinjuku, Tokyo, Japan

Break

Session 5: EUV Sources

Optimization of Laser-produced Plasma Light Sources for EUV Lithography (P6)
Mark Tillack and Yezheng Tao
University of California, San Diego, La Jolla, CA

High Brightness EUV & Soft-X-ray MPP Discharge Source System Development (P27)
Peter Choi[ab], Sergey V. Zakharov[ab+], Raul Aliaga-Rossel[a], Aldrice Bakouboula[a], Otman Benali[ab], Philippe Bove[a], Michèle Cau[a], Grainne Duffy[a], Blair Lebert[b], Ouassima Sarroukh[b], Clement Zaepffel[a], Vasily S. Zakharov[b]
[a] *Nano-UV sas, Villebon/Yvette, France*
[b] *EPPRA sas, Villebon/Yvette, France*
[+] *also with NRC Kurchatov Institute, Moscow, Russia*

EQ-10 Electrodeless Z-Pinch EUV Source for Metrology Applications
Deborah Gustafson, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Matthew J. Partlow, Paul A. Blackborow (P38)
Energetiq Technology, Inc., Woburn, MA, USA 01801

Progress on Liquid Metal Collector Mirrors as Robust Plasma Facing EUV and Soft X-ray Optics (P18)
Kenneth Fahy, Fergal O'Reilly, Enda Scally, Padraig Dunne, Paul Sheridan
University College Dublin, Dublin, Ireland

1st/2nd Generation Laser-Produced Plasma Light Source System for HVM EUV Lithography (P34) (Invited Paper)
Hakaru Mizoguchi[1], Tamotsu Abe, Yukio Watanabe, Takanobu Ishihara, Takeshi Ohta, Tsukasa Hori, Tatsuya Yanagida, Hitoshi Nagano, Takayuki Yabu, Shinji Nagai, Georg Soumagne, Akihiko Kurosu, Krzysztof M. Nowak, Takashi Suganuma, Masato Moriya, Kouji Kakizaki, Akira Sumitani, Hidenobu Kameda[1], Hiroaki Nakarai[1], Junichi fujimoto[1]
EUVA/Komatsu (Japan): Hiratsuka, Kanagawa, Japan
[1]*Gigaphoton (Japan): Oyama, Tochigi, Japan*

Adjourn at 4 PM

Thursday, June 16, 2011

9:00 AM Welcome and Announcements

Vivek Bakshi
EUV Litho, Inc, Austin, TX USA

Session 6: EUVL R&D Status

Panelists:

Hiroo Kinoshita –Japan (Hyogo University)

Bryan, B. Y. Shew – Taiwan (NSRCC)

Jinho Ahn – Korea (Hanyang University)

Padraig Dunne – Europe (University College Dublin)

Vivek Bakshi – USA (EUV Litho, Inc.)

Break

Session 7: EUVL Mask

Developing a New State of the Art EUV Mask Imaging Research Tool at Berkeley (P11) (Invited Paper)
Kenneth Goldberg, Iacopo Mochi, Eric M. Gullikson, Erik H. Anderson, Patrick P. Naulleau
Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Overview of EUM Mask Inspection Systems in NewSUBARU (P15) (Invited Paper)
Hiroo Kinoshita, Tetsuo Harada and Takeo Watanabe
Center for EUV Lithography, University of Hyogo, Japan

Development Status of EUVL Mask Blank and Substrate (P12) (Invited Paper)
Kazunobu Maeshige
Central Research Center, Asahi Glass Co. Ltd., JAPAN

EUV Mask Production and Cleaning (P13) (Invited Review Paper)
David N. Ruzic, Wayne Lytle, Daniel Andruczyk
UIUC, Urbana-Champaign, IL, USA

Lunch (Holokai Pavilion)

Session 8: EUV Resist and Resist Outgassing

Recent Progress in Nano-space Radiation Chemistry Research on Sensitivity Enhancements of EUV Resists (P37) (Invited Paper)
Seiichi Tagawa[1,2]
[1] *The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, Japan*
[2] *Japan Science and Technology Agency, CREST, c/o Osaka University, Ibaraki, Osaka, Japan*

Challenges in Development and Construction of Metrology, Calibration, and Resist Testing Tools for the Implementation of EUV Lithography (P3)
Rupert C. C. Perera
EUV Technology, Martinez, CA, USA

Cleaning of Capped Multi-Layer Samples and Cleaning with Hydrogen using the Evactron® De-Contaminator (P23)
Christopher G. Morgan and Ronald Vane
XEI Scientific, Inc., Redwood City, CA, USA

Mass Spectrometer Characterization of Reactions in Photoresists Exposed to Extreme Ultraviolet Radiation (P29)
Chimaobi Mbanaso, Seth Kruger, Craig Higgins, Yashdeep Khopkar, Alin Antohe, Brian Cardineau, Gregory Denbeaux
College of Nanoscale Science and Engineering, University at Albany, Albany, New York, USA

Session 9: EUV Optics

Status of Multilayer Coatings for EUV Lithography (P25) (Invited Review Paper)
Yuriy Platonov[1], Eric Louis[2], Torsten Feigl[3], Sergiy Yulin[3], Jim Rodriguez[1], Michael Kriese[1]
[1] *Rigaku Innovative Technologies, Auburn Hills, MI, USA,*
[2] *FOM Rijnhuizen, Nieuwegein, The Netherlands*
[3] *Fraunhofer IOF, Jena, Germany*

Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics (P32) (Invited Review Paper)
Regina Soufli
Lawrence Livermore National Laboratory, Livermore, California, US

Developing Reflective Multilayer Coatings, an Enabling Component of Extreme Ultraviolet Lithography and Beyond (P24) (Invited Paper)
E. Louis[1], S. Müllender[2], and F. Bijkerk[1,3]
[1]*FOM Rijnhuizen, Nieuwegein, The Netherlands,*
[2]*Carl Zeiss SMT AG, Oberkochen, Germany*
[3] *MESA+ Institute for Nano Technology, University of Twente, The Netherlands*

WORKSHOP SUMMARY

EUVL Workshop Summary and Announcements
Vivek Bakshi
EUV Litho Inc, Austin, TX, USA

5: 00 PM Session 11: Poster Session

Thin Half-tone Phase Shift Mask Stack for Extreme Ultraviolet Lithography (P19)
[1]Inhwan Lee, [2]Sangsul Lee, [2]Jae Uk Lee, [2]Chang Young Jeong,[3]Sunyoung Koo, [3]Changmoon Lim, and [1,2]Jinho Ahn
[1]Department of Nanoscale Semiconductor Engineering,
[2]Department of Material Science and Engineering,Hanyang University, Seoul 133-791, Korea
[3]Memory Research & Development Division, Hynix Semiconductor Inc., San 136-1 Ami-ri, Bubal-eub, Icheon-si, Kyungki-do, 467-701, Korea

EUVL Flare Modeling with an Improved Accuracy for Feasibility Study of Sub-22nm HP Node (P21)
Junhwan Lee, Sangheon Lee and Ohyun Kim
Department of Electronic and Electrical Engineering, Pohang University of Science and Technology, Korea

B_4C/Si based EUV Multilayer Mirror with Suppressed Reflectivity for CO_2 Laser Radiation (P4)
V.V. Medvedev[1,2], A.E. Yakshin[1], R.W.E. van de Kruijs[1], V.M. Krivtsun[2], A.M. Yakunin[3], F. Bijkerk[1,4]
[1] FOM Institute for Plasma Physics, Nanolayer- Surface and Interface Physics department, Nieuwegein, The Netherlands
[2] Institute for Spectroscopy RAS, Troitsk, Moscow region, Russia
[3] ASML, Veldhoven, The Netherlands
[4] MESA+, University of Twente, Enschede, The Netherlands

EUV Spectra of Gadolinium Laser Produced Plasmas (P16)
Colm O' Gorman[1], Takamitsu Otsuka[2], Takeshi Higashiguchi[1], Akira Endo[3], Tony Donnelly[1], Bowen Li[1], Thomas Cummins[1], Deirdre Kilbane[1], Emma Sokell[1], Padraig Dunne[1] and Gerry O' Sullivan[1]
[1] School of Physics, University College Dublin, Dublin 4, Ireland
[2] Department of Advanced Interdisciplinary Sciences and Centre of Optical Research and Education (CORE), Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi, 321 – 8585, Japan
[3] Forschungszentrum Dresden, Bautznew Landstrs. 400, Dresden D-01238, Germany

Laser Plasma Pumping by Variable-length CO_2 Laser Pulses (P20)
Thomas Cummins, Marie Mazoyer, Gerry O'Sullivan, Padraig Dunne, Emma Sokell, Fergal O'Reilly, Colm O'Gorman and Tony Donnelly
Atomic, Molecular and Plasma Spectroscopy group, School of Physics, University College Dublin, Dublin, Ireland

Gas-based Spectral Filter for Mitigating 10.6 μm Radiation in CO_2 Laser Produced Plasma Extreme Ultraviolet Sources (P28)
Chimaobi Mbanaso[1], Gregory Denbeaux[1], Alin Antohe[1], Horace Bull[1]
Frank Goodwin[2], Ady Hershcovitch[3]
[1] College of Nanoscale Science and Engineering, University at Albany, Albany, New York, USA
[2] SEMATECH, Albany, New York, USA
[3] Brookhaven National Laboratory, Upton, New York, USA

6:00 Dinner and Adjourn

Friday, June 17, 2011

EUVL Workshop Steering Committee Meeting

8:30 AM	Breakfast
9:00 -10: 00 AM	EUVL Workshop Steering Committee Meeting

Abstracts

(Listed by Paper number)

P -1

EUV Lithography and EUVL Sources: From the Beginning to NXE and Beyond

Vadim Banine

ASML, Eindhoven, Netherlands

EUV lithography has come a long way over the last two decades starting from small field demonstration systems through full field alpha tool scanners installed by ASML in CNSE, Albany, USA and IMEC, Leuven, Belgium to EUV pre-production tools installed at multiple customer locations. These tools provide invaluable learning for EUVL chip-makers in early production as well as for EUV tools to be shipped in a few years' time.

EUV source is an integral part of the EUVL system, which for the last 2 decades evolved from the laboratory type installations into production worthy machines.

In the presentation a short summary of status of EUV lithography will be followed by a presentation of a potential EUV roadmap down to single digit imaging nodes. A historic overview of the EUV source evolution and revolution will be given. A path to extend the current lithography to a shorter wavelength will be shown.

Presenting Author

Dr. Vadim Banine is currently Director of Research at ASML. He has worked for ASML since 1996 and has held positions of Senior Research Manager, Head of ASML laboratory and external project co-ordinator for ASML research department. He received his PhD in 1994 from Eindhoven University of Technology, The Netherlands (TUE). The subject of his PhD work was the diagnostics of combustion plasma. From 1995-96 he did his postdoctoral work at TUE in the Laboratory of Heat and Mass Transfer. He has over 40 publications and over 100 patens. He is also the winner of ASML patent award.

P2

Development and Optimisation of EUV Emission from Laser Produced Plasmas

Gerry O'Sullivan

University College Dublin, Dublin, Ireland

Early work relevant to the development and optimisation of EUV emission from laser produced plasmas will be reviewed. The physics underlying the behaviour of plasmas responsible for emission at 13.5 nm, the different needs for sources for metrology and high volume manufacturing and how this influences the choice of operating conditions in order to optimise conversion efficiencies will be discussed. Current and recent work on effects of target composition and geometry, laser pulse profile and power density etc will be presented and comparisons will be made between theoretical and experimental results.
In addition, the results of recent work, both experimental and theoretical, on sources for 6.x nm operation will be presented and the optimum plasma conditions will be identified.

Presenting Author

Prof. Gerry O'Sullivan obtained his PhD from University College Dublin (UCD) in 1980 for work on the spectroscopy of laser produced plasmas of medium to high Z elements that included the first observation the unresolved arrays now studied as emission sources for EUVL at 13.5 and 6.x nm, changes in their EUV emission due to opacity and the application of higher Z plasmas as sources of EUV continuum radiation. After a brief period at the University of Maryland and National Bureau of Standards he returned to Dublin where he was employed at Dublin City University from 1981 before moving to a lectureship at UCD in 1986. He is currently a Professor at UCD and served as Head of the School of Physics from 2002 - 2008. His research interests include EUV and soft x-ray continuum generation from laser produced plasmas and application to inner shell photoabsorption studies of atoms, ions and molecules, investigation of unresolved transition arrays (UTA) and their application as high brightness EUV sources, determination of the electronic structure of medium and high Z ions and spatial and temporal characterisation of laser produced plasmas.

In recent years, aided primarily by funding from Science Foundation Ireland, this work has focussed strongly on studies relevant to the development of EUVL sources. He has published more than 110 papers and is a member of the editorial board of European Journal of Physics. He is a member of the Royal Irish Academy and a Fellow of the Institute of Physics.

P3

Challenges in Development and Construction of Metrology, Calibration, and Resist Testing Tools for the Implementation of EUV lithography

Rupert C. C. Perera

EUV Technology, 837 Arnold Drive Suite 400, Martinez, CA 94553, USA

Extreme Ultraviolet (EUV) Lithography is the most promising approach for reaching the 22 nm node and beyond in the manufacturing of silicon devices. One of the principal challenges in the ongoing EUVL research effort is the development of necessary at wavelength metrology tools and resist outgassing and testing tools.

EUV Technology has pioneered the development of several of stand-alone inspection, metrology, calibration, and resist outgassing testing tools for EUV lithographic applications that can be operated in a clean room environment on the floor of a fab. EUV Technology is the world’s leading manufacturer of EUV metrology and testing tools.

An overview of our planed development activities HVM metrology tools for EUV Lithography will be presented along with the challenges in developing these HVM tools in order to support the successful implementation of EUV Lithography for the 22nm node will be discussed. In addition, performance of our commercially available metrology and testing tools that have been fully operational for many years with very good up time will be presented.

P4

B_4C/Si based EUV Multilayer Mirror with Suppressed Reflectivity for CO_2 Laser Radiation

V.V. Medvedev[1,2], A.E. Yakshin[1], R.W.E. van de Kruijs[1], V.M. Krivtsun[2], A.M. Yakunin[3], F. Bijkerk[1,4]

[1] FOM Institute for Plasma Physics, nanolayer- Surface and Interface Physics department, Nieuwegein, The Netherlands
[2] Institute for Spectroscopy RAS, Troitsk, Moscow region, Russia
[3] ASML, Veldhoven, The Netherlands
[4] MESA+, University of Twente, Enschede, The Netherlands

We have developed a multilayer mirror for extreme ultraviolet (EUV) radiation which has near-zero reflectance for CO_2 laser radiation (10.6 μm). The EUV reflecting multilayer coating is based on alternating B_4C and Si layers. Substantial transparency of these materials with respect to the infrared radiation allows utilizing the multilayer coating in a resonant absorbing structure for 10.6 μm. We have integrated the multilayer structure with a well known quarter-wavelength thin film absorber. Experimental samples were manufactured using magnetron sputtering deposition technique. The samples demonstrate suppression of the infrared radiation by more than two orders of magnitude. At the same time EUV peak reflectance amounts 45% at 13.5 nm, with FWHM being about 0.284. Therefore such a mirror could replace a standard Mo/Si mirror in an EUV lithography tool to form an efficient solution for the suppression of unwanted CO_2 laser radiation.

Presenting Author

Viacheslav Medvedev is PhD student in the department of nanolayer Surface and Interface physics at the FOM Institute for Plasma Physics Rijnhuizen. He obtained the master degree in applied physics and mathematics from Moscow Institute of Physics and Technology in 2009. His research interests focus on optical properties of nanostructured materials, optical spectroscopy and plasma sources of radiation.

P5

Rare-Earth Plasma EUV Source at 6.7 nm for Future Lithography

Takeshi Higashiguchi[1,2], Takamitsu Otsuka[1], Noboru Yugami[1,2], Deirdre Kilbane[3], Thomas Cummins[3], Colm O'Gorman[3], Tony Donnelly[3], Padraig Dunne[3], and Gerry O'Sullivan[3], Weihua Jiang[4], and Akira Endo[5]

[1]Department of Advanced Interdisciplinary Sciences, and Center for Optical Research & Education (CORE) Utsunomiya University, Utsunomiya, Tochigi, Japan
[2]Japan Science and Technology Agency, Kanagawa, Saitama, Japan
[3]School of Physics, University College Dublin, Belfield, Dublin, Ireland
[4]Department of Electrical Engineering, Nagaoka University of Technology, Nagaoka, Niigata, Japan
[5]Waseda University, Research Institute for Science and Engineering, Waseda University, Shinjuku, Tokyo, Japan

In recent years, dense plasmas have been focused on as high efficiency and high power sources of EUV radiation. The development of sources of EUV emission with a wavelength less than 10 nm is a subject of considerable interest. Wavelengths shorter than 10 nm are especially useful for next generation semiconductor lithography toward the final stage beyond the 13.5-nm EUV source and for other applications, such as material science and biological imaging in the water window. In particular, EUV emission can be coupled with a Mo/B_4C or La/B_4C multilayer mirror with a reflectivity coefficient of 40% at 6.5-6.7 nm.

We have demonstrated a laser-produced plasma extreme ultraviolet source with peak emission around 6.5-6.7 nm, which was attributed to hundreds of thousands of near-degenerate resonance lines in an unresolved transition array (UTA) [1]. We have observed the variation of spectral behavior of resonance line emission in Gd plasmas in the 6.7 nm region when different laser wavelengths were used to change the critical electron densities [2]. As the effects of self-absorption on the resonance lines in the Gd plasmas are large, it is important to produce low-density plasma using long laser wavelength and/or low-initial target concentration of Gd. The spectrum based on the low initial density target was narrower and more intense than that of the pure solid target. As a result, the maximum CE was observed to be about 1.8% by dual Nd:YAG laser-produced low-density plasmas with a 30% low initial density target of the solid Gd [3]. We show the experimental configuration required to optimize the EUV plasma source.

[1] T. Otsuka *et al*., Appl. Phys. Lett. **97**, 111503 (2010); G. Tallents *et al*., Nat. Photonics **4**, 809 (2010).
[2] T. Otsuka *et al*., Appl. Phys. Lett. **97**, 231503 (2010).
[3] T. Otsuka *et al*. (to be submitted).

P6

Optimization of Laser-produced Plasma Light Sources for EUV Lithography

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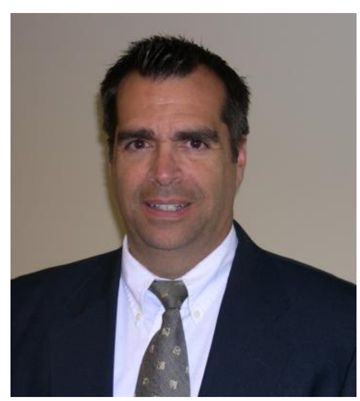
Comprehensive studies of laser-produced tin plasmas in regimes of relevance to EUV lithography have been carried out at the University of California in San Diego over the past decade. These studies have led to several important discoveries relevant to applications in both high-volume manufacturing and actinic metrology and mask inspection. In this presentation we review results of experiments exploring the plasma dynamics and resulting light and particle emission as a function of the key laser and target parameters, including intensity, spot size, wavelength, pulse-length, pre-pulse and multi-pulse (pulse-train). Our research shows that control of the plasma density profile is the most influential pathway toward improved commercial systems:

(1) lower critical density makes CO_2 laser-produced Sn plasma more efficient, with higher spectral purity than Nd:YAG lasers;
(2) non-isothermal expansion of CO_2 laser-Sn plasma makes it insensitive to laser pulse duration;
(3) the expanded corona in confined CO_2 laser-produced Sn plasmas enables higher in-band CE;
(4) the small corona produced with small focal spots enables long Nd:YAG laser pulses to drive a high-brightness EUV metrology source; and
(5) formation of gentler plasma density profiles helps reduce ion kinetic energy.

Presenting Author



Mark Tillack received his Ph.D. in nuclear engineering in 1983 from the Massachusetts Institute of Technology and has been involved in energy research since that time. He was a member of the UCLA Institute for Plasma and Fusion Research from 1983-1994 where he held the title Principal Institute Scientist. From 1994 until the present he has been a member of the Mechanical and Aerospace Engineering department at UC San Diego, and is currently the Associate Director of the Center for Energy Research. His research interests include laser-produced plasmas and laser ablation plume physics and applications.

P7

Atomic and Radiative Processes in Plasmas for the Shorter Wavelength Extreme Ultra-violet (EUV) Light Sources

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Laser and discharge produced plasmas have attracted attention for their application to the light sources for the microlithography. Although, the output power and efficiency have improved significantly, an increase of the source power beyond 200W is still a challenge. Light sources with shorter wavelengths are also interested for the future microlithography. Numerical simulation is useful for the optimization of such light sources, however, present theoretical model should also be improved in terms of the calculation of radiative transfer, to obtain better agreement between experimental and calculated spectra, as well as to predict properties of the light source with high accuracy.

The emission from 4d-4f transition array is shown to be scalable to λ=6.5nm, however,the light sources with higher efficiency, which can be operated at lower pumping intensity will be useful. Wavelengths and transition probabilities of intense emission lines such those from resonant 1s-2p, 2p-3d, and 3d-4f transitions from multiple charged ions are investigated, and possibilities of their application to the light sources are discussed.
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Presenting Author

Akira Sasaki received the Dr. Eng. degree in energy science from Tokyo Institute of Technology, Tokyo, Japan in 1991. He joined Japan Atomic Energy Agency in 1996. He has been studying modeling and simulation of atomic processes of Xe and Sn plasmas of the EUV source for lithographic applications since 2002.

P8

EUV Interference Lithography for 1X nm

Takeo Watanabe, Yuya Yamaguchi, Takuro Urayama, Naohiro Matsuda,
Tetsu Harada and Hiroo Kinosita

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Spontaneous achievement of high sensitivity and low line edge roughness in EUV resist is one of the top three issues in EUVL technology to lead to high volume manufacturing of the semiconductor device. In addition, there is no exposure tool to replicate the resist pattern width of 20 nm and below with high stability. Thus, EUV interference lithographic tool has been installed at BL9 beamline at NewSUBARU synchrotron radiation facility to evaluate EUV resist for 20 nm and below. A 10.8-m-long undulator was employed as a light source. This light source can produce suitable coherence length and high intensity flux for EUV interference lithography (EUV-IL). In EUV-IL, fabrication of transparent grating which has two grating windows with fine resolution is a key technology. Employing SiO_2 hard mask process to obtain fine pattern and center stop process to obtain intensity distribution on a wafer, 30 nm L/S transparent grating was fabricated. In addition, decreasing vibration effect, we succeeded with replicating 20 nm, 17.5 nm and 15 nm L/S resist patterns using EUV-IL. Using this system, it is strongly expected that EUV resist development which can satisfy the specification would be accelerated.

P9

EUV R&D Status-Taiwan

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National Synchrotron Radiation Research Center (NSRRC), Taiwan

Overview of EUVL R&D Status in Taiwan.

Presenting Author

Bryan, B.Y. Shew received his PhD in material science (1996) and B.S. (1989) in mechanical engineering from the National Cheng-Kung University (NCKU), Taiwan. He is at present the leader of Industrial Application Office of National Synchrotron Radiation Research Center (NSRRC), and the spokesperson of Nano- lithography beamline at NSRRC. He is also the coordinator of the EUVL programs at NSRRC both from the academics and industrials. His primary research area lies in Nanofabrication, Nano/Micro system, and advanced battery technologies.

P10

Radiative Hydrodynamic Simulation of Laser-produced Tin Plasma for Extreme Ultraviolet Lithography

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3) Quantum Beam Science Directorate, Japan Atomic Energy Agency, 8-1 Umemidai, Kizugawa Kyto 619-0215 Japan
4) EUVA

In order to investigate the conversion efficiency (CE) from laser to extreme ultraviolet (EUV) light, we have developed one and two-dimensional radiation hydrodynamic simulation codes, and applied them to analysis of the EUV emission from tin plasmas. We confirmed that the laser absorption fraction for CO2 irradiation on tin plate is almost constant with the long laser pulse duration, and the resulted EUV CE was estimated to be 2.0-3.0%. Also we simulated the double pulse irradiation scheme for improving EUV CE. In this presentation, we will show our results of radiation hydrodynamic simulation for the double pulse irradiation on tin droplet for laser-produced plasma (LPP) system using CO2 laser with various droplet and laser conditions.

P11

Developing a New State of the Art EUV Mask Imaging Research Tool at Berkeley

Kenneth Goldberg, Iacopo Mochi, Eric M. Gullikson, Erik H. Anderson, Patrick P. Naulleau

Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley,

We are developing a multi-generation EUV mask-imaging microscope based on the proven optical principle of the SEMATECH Berkeley Actinic Inspection Tool (AIT), but surpassing it in every performance metric. The new tool design will enable research on multiple generations of EUV lithography technology, down to 8 nm and beyond.

The wavelength-specific properties of EUV reticles limit the effectiveness of all non-EUV inspection technologies, and the differences between EUV and non-EUV measurements are likely to increase in future nodes.

The new microscope will greatly surpass the capabilities of the AIT, providing variable, high resolution imaging up to 0.625 4xNA, or higher, with customizable coherence control, and the ability to measure across a range of azimuthal angles of incidence, to emulate a stepper's ring-field. We will discuss the expected imaging properties.

Many in the EUV community are now looking forward to opportunities at shorter EUV wavelengths, near 6.5 nm. We will describe the new microscope's upgradable optical system and its potential for operation at these short wavelengths.

We are now working to bring this capability online in late 2012, well in advance of commercial tool availability.

Presenting Author

Kenneth A. Goldberg (A.B. in Physics and Applied Math; M.A. and Ph.D. in Physics, University of California, Berkeley) is a staff physicist at Lawrence Berkeley National Laboratory's Center for X-Ray Optics. He specializes in the development of technologies for EUV wavelengths, including lithography, interferometry, mask inspection, and synchrotron radiation beamlines. He has published over 100 papers on science and technology for EUV wavelengths and has 12 patents.

P12

Development Status of EUVL Mask Blank and Substrate

Kazunobu Maeshige

Central Research Center, Asahi Glass Co. Ltd., JAPAN

Asahi Glass has been developing the mask blank and the polished substrate for EUV (extreme ultra violet) lithography since 2003, including the developments of all essential materials and processes: the low thermal expansion material (LTEM), the material developments of the reflective, capping and absorber films, the process developments of the substrate polishing, the cleaning, the film deposition and the resist film coating processes. In this paper, we present the current development status of the full-stack EUV mask blank and polished substrate which are most suitable for EUV lithography process developments with EUV pre-production exposure tools. We are going to report the development progress of the reflective multilayer-coated LTEM substrate by showing the critical performances comparatively with those of 2010 achievements, which include the substrate flatness, the EUV optical properties of the Mo/Si reflective layers and the defect of LTEM substrate and reflective layer. The performances of the Ta-based absorber and the resist films will be reported as well to show the readiness of the EUV mask blank suitable for process developments of the EUV lithography.

P13

EUV Mask Production and Cleaning

David N. Ruzic, Wayne Lytle, Daniel Andruczyk
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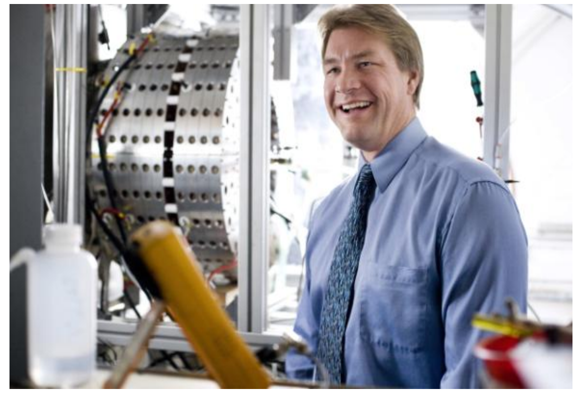
One of the critical issues still facing the implementation of extreme ultraviolet lithography (EUVL) into mainstream manufacturing for integrated circuit (IC) and photomask production is cleanliness. EUV photons at 13.5 nm are easily absorbed by many species, including dust, thin film layers, and other debris present in the path of the photons. Carrying out EUVL inside a vacuum helps reduce the amount of photon loss for illumination, however contamination in the system is unavoidable, especially due to carbon growth on the multilayer mirror collectors triggered by the EUV itself and to soft defects in the form of organic contamination on the mask. Traditional cleaning methods employ the use of wet chemicals to etch contamination off of a surface, however this is limited in the sub-micron range of contaminant particles due to lack of transport of sufficient liquid chemical to the surface in order to achieve satisfactory particle removal. According to the International Technology Roadmap for Semiconductors (ITRS), the photomask must be particle free at inspection below 30 nm. However, when analyzing the ability of traditional methods to meet the cleaning needs set forth by the ITRS, these methods fall short and often add more contamination to the surface targeted for cleaning. With that in mind, a new cleaning method is being developed to supplant these traditional methods. Preliminary research into a plasma-based method to clean organic contaminants from lithographic materials constructed an experimental device that demonstrated the removal of both polystyrene latex nanoparticles (representing hydrocarbon contamination) in the range of 30 nm to 500 nm, as well as the removal of 30 nm carbon film layers on silicon wafers. This research, called Plasma-Assisted Cleaning by Metastable Atomic Neutralization (PACMAN) will be described in detail as well as an overview of mask production techniques.

Presenting Author

Dr. David N. Ruzic is the Director of the Center for Plasma Material Interactions at the University of Illinois at Urbana-Champaign. He is a full professor in the Department of Nuclear, Plasma, and Radiological Engineering and affiliated with the Department of Electrical and Computer Engineering and the Department of Physics, having joined the faculty in 1984. His current research interests center on plasma processing for the microelectronics industry (deposition, etching, EUV lithography and particle removal) and on fusion energy research. Prof. Ruzic is a Micron Professor at Illinois and a Fellow of the American Nuclear Society and of the

American Vacuum Society. He is the author of the AVS monograph, *Electric Probes for Low Temperature Plasmas*, numerous book chapters, patents, and over 100 refereed journal articles. He obtained his PhD and MS in Physics from Princeton University, and his BS degree in Physics and Applied Math from Purdue University. He really enjoys teaching and tries to blow something up during every lecture.



P14

R & D status in EUVL program in Japan

Hiroo Kinoshita

Center for EUV Lithography, University of Hyogo

A new consortium for developing an infrastructure of EUV lithography was advertised for by NEDO. In this consortium, mask inspection equipments and resist with low outgas for 16 nm node and 11nm node will be developed by 2013 and 2016, respectively. The detailed plan will be introduced in this workshop.

Presenting Author

Hiroo Kinoshita received Bachelor and Master of engineering degree in Mechanical Engineering from KEIO University in 1972 and1974, respectively. After that, he worked for NTT. He had developed a X-ray Proximity Lithography, Mask inspection tool using EB and Extreme Ultraviolet Lithography. In 1995 he moved to Himeji Institute of Technology (Now it called University of Hyogo). He received a doctor degree from KEIO university in 2004.

P15

Overview of EUM Mask Inspection Systems in NewSUBARU

Hiroo Kinoshita, Tetsuo Harada and Takeo Watanabe

Center for EUV Lithography, University of Hyogo

We have developed two types of inspection systems.

One system called EUVM was used to inspect pattern defect on finished masks and phase defects in Mo/Si coated substrates on Ultra Low Expansion (ULE) glass. We also have fabricated programmed phase defects on the mask blanks used for inspection. In this year, this system has observed some mask samples repaired by Ga^+ and H^+ focused ion beam.

Another system called CSM (Coherent Scatterometry Microscope) is under developping for the defect inspection and CD measurement of 22-nm-node EUV masks. Up to now, some undersize defects in a line-and-space pattern were clearly observed and the CD of a periodic L&S pattern was accurately measured. The 3☐ CD accuracy is 0.32 nm, which satisfies the ITRS specifications for the hp-22-nm node. Furthermore, a 13.5-nm HHG source based on a commercial 30-fs laser system (Spectra Physics) has already been built. Experimental results using this source will be reported.

Presenting Author

Hiroo Kinoshita received Bachelor and Master of engineering degree in Mechanical Engineering from KEIO University in 1972 and1974, respectively. After that, he worked for NTT. He had developed a X-ray Proximity Lithography, Mask inspection tool using EB and Extreme Ultraviolet Lithography. In 1995 he moved to Himeji Institute of Technology (Now it called University of Hyogo). He received a doctor degree from KEIO university in 2004.

P16

EUV Spectra of Gadolinium Laser Produced Plasmas

Colm O' Gorman[1], Takamitsu Otsuka[2], Takeshi Higashiguchi[1], Akira Endo[3], Tony Donnelly[1], Bowen Li[1], Thomas Cummins[1], Deirdre Kilbane[1], Emma Sokell[1], Padraig Dunne[1] and Gerry O' Sullivan[1]

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[3] Forschungszentrum Dresden, Dresden, Germany

EUV emission at 6.7nm may be coupled with a Mo/B_4C mirror to produce a source for EUVL at that wavelength. Emission from 4d – 4f and 4p – 4d transitions in Gd ions have been shown to be a possible source at this wavelength region[1,2].The dependence of the spectral behaviour and conversion efficiencies of gadolinium laser produced plasmas on laser intensity and target composition was investigated. A 1064nm, Nd:YAG with a pulse length of 160 ps and a maximum energy output of 500mJ, delivering a maximum on target power density of 1×10^{13}W/cm^2 was used and spectra from the plasma was analysed using a 2 metre grazing incidence spectrometer . Absolute intensities in the in band region was measured using a photo diode coupled with a Mo/B_4C mirror allowing conversion efficiencies to be calculated. These results are compared to atomic code calculations that predicted a maximum in band emission at a T_e = 144 eV at $N_e = 10^{21}$ cm^{-3} [3].

1 - EUV spectra of Gd and Tb ions excited in laser-produced and vacuum spark plasmas –S. S. Churilov, R. R. Kildiyarova, A. N. Ryabtsev, and S. V. Sadovsky, *Phys. Scr.* **80** 045303 (2009)

2 – Systematic Investigation of self – absorption and conversion efficiency of 6.7nm extreme ultraviolet sources – Takamitsu Otsuka, Deirdre Kilbane, Takeshi Higashiguchi, Noboru Yugami,
Toyohiko Yatagai, Weihua Jiang, Akira Endo, Padraig Dunne, and Gerry O'Sullivan, *Appl. Phys. Lett.* **97,** 231503 (2010)

3 – Extreme ultraviolet emission spectra of Gd and Tb ions – D. Kilbane and Gerry O'Sullivan , *J. Appl.Phys.* **108,** 104905 (2010)

P17

EUV Lithography Simulation for the 16 nm Node

Eun-Jin Kim, GukJin Kim, Seong-Sue Kim*, Han-Ku Cho*, Jinho Ahn**, Ilsin An, and Hye-Keun Oh

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*Samsung Electronics Co., LTD., Hwasung-City, Gyeonggi-Do, Korea
**Department of Material Science & Engineering, Hanyang University, Seoul, Korea

Over the years Extreme ultra-violet lithography (EUVL) has made a lot of progress. And EUV was believed to be one of the strong candidates for the patterning of 22 nm node and below. But, EUV process has still many problems in EUV source, mask, resist and process. Expressly, the EUV light shining 6-8 degrees oblique incidence to the mask on 16 nm node, do not get the desired critical dimension (CD) because the shadow effect influences to the pattern. This shadow effect in the EUVL mask is an important factor that decreases the contrast of the aerial image and, as a result, causes a line width variation. Thus, many researchers studied the EUV process modification for reducing the shadow effect such as the off-axis illumination (OAI), phase-shift mask (PSM) and optical proximity correction (OPC).

Thus, in this paper, we study the optimized EUV process for 16 nm node. First, we changed the incident angle such as 6 degree and 8 degree for reduction of shadow effect. Incident angle into the mask for the pole location are not the same in spite of the light shining with 6-8 degrees oblique incidence to mask from mirror. We calculated the incident angles for the various illumination pole conditions of circle and dipole. The influence of the flare in EUV process is also known to be very serious. Thus, secondly, we compared the effect of various flare. Moreover, we confirm the horizontal-vertical CD for the incident angle in line and space (L/S) and contact hole (CH) patterns. Finally, we study the OPC for the various patterns to get the target CD of 16 nm.

P18

Progress on Liquid Metal Collector Mirrors as Robust Plasma Facing EUV and Soft X-ray Optics

Kenneth Fahy, Fergal O'Reilly, Enda Scally, Padraig Dunne, Paul Sheridan

UCD, Dublin, Ireland

Recent work in UCD has centred on the development of a liquid metal coating process for EUV and soft X-ray collector optics. The work involves using a variety of liquid metals coated on a solid metal substrate of the appropriate form. We demonstrate that a stable thin coating film on the interior surface of a rotating optic substrate is possible, and this offers promise as a solution to the problem of producing an atomically flat reflector that remains unspoiled in front of a multi-kilowatt EUV plasma. We report on the results of EUV tests carried out on a simple focusing liquid metal mirror, with xenon and liquid tin discharge plasmas, and laser plasma EUV sources.

Presenting Author

Padraig Dunne received his PhD from University College Dublin in experimental atomic physics in 1994. His research interests include Laser Produced Plasmas (LPPs) as sources of ions and continuum radiation for photoabsorption spectroscopy, as sources of EUV radiation for next generation photolithography and microscopy/imaging. He has co-authored over 40 peer-reviewed journal articles and a similar number of conference papers. He is currently Graduate School Director in the UCD College of Engineering, Mathematical and Physical Sciences and an associate professor in the UCD School of Physics. He is a member of SPIE and of the Institute of Physics.

P19

Thin half-tone phase shift mask stack for Extreme Ultraviolet Lithography

[1]Inhwan Lee, [2]Sangsul Lee, [2]Jae Uk Lee, [2]Chang Young Jeong, [3]Sunyoung Koo, [3]Changmoon Lim, and [1,2]Jinho Ahn

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Extreme ultraviolet lithography (EUVL) using 13.5nm wavelength is the most promising patterning technology to be adopted for 22nm half pitch (hp) and below. Since EUV light is strongly absorbed by most materials, reflective optics should be applied. Mask shadowing effect is an unique phenomenon caused by using mirror-based mask with oblique incident angle of light. This results in a horizontal-vertical (H-V) bias, an ellipticity in the contact hole pattern and eventually critical dimension (CD) non-uniformity. Reducing the absorber thickness is the most effective method to minimize the mask shadowing effect, but can deteriorate mask image contrast. A phase shift concept has been suggested as a potential solution to improve the image contrast with a thinner absorber stack.

In this paper, we present an optimized thin half-tone phase shift mask (HT-PSM) stack having an ability to control reflectivity while maintaining total absorber stack thickness to 40.5 nm which satisfies the out-of-phase condition in the case of using tantalum nitride (TaN) as an absorber. By applying molybdenum (Mo) which has a similar delta (δ) but an attenuated beta (β) value compared with TaN absorber, the reflectivity can be controlled by adjusting Mo thickness. However, the optimum absorber stack structure is quite different depending on pattern widths, pitches, and illumination conditions. The proposed PSM for 22nm hp L/S pattern, for example, consists of 16.5nm TaN absorber layer and 24nm thick Mo phase shifter on 2nm ruthenium (Ru) capped 40 pairs of Mo/Si multilayer. This Mo phase shifter results in an include 27.5% improvement in mask error enhancement factor (MEEF) value and 1.9nm reduction in horizontal-vertical bias (H-V bias) compared to conventional binary intensity mask (BIM) under 0.32NA illumination condition. And 10~12% improved image contrast was obtained with 11~17% reflectivity on the absorber stack, which corresponds to 24~29nm Mo thickness, through aerial image simulation. And the experimental results on the HT-PSM preparation will be discussed during the presentation.

P20

Laser Plasma Pumping by Variable-length CO_2 Laser Pulses

Thomas Cummins, Marie Mazoyer, Gerry O'Sullivan, Padraig Dunne, Emma Sokell, Fergal O'Reilly, Colm O'Gorman and Tony Donnelly

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Research to date [1] has identified CO_2 laser produced plasmas (LPPs) of Sn as a viable Extreme Ultraviolet Lithography (EUVL) source candidate. CO_2 LPPs have demonstrated the potential to generate in-band radiation at lower power densities and reduced energy consumption by comparison to Nd:YAG generated plasmas, due in part to reduced opacity effects [2]. Interactions with pre-formed plasmas have the potential to enhance the coupling of CO_2 radiation with the target. Pulse shortening techniques of the CO_2 temporal profile have been reported [3] and shown possible further improvements in CE values [4]. Previous techniques have demonstrated pulse shaping. However, many of these methods are either quite complex or expensive, without achieving pulse durations below 20ns.

We outline research undertaken to optimise the conversion efficiency (CE) in CO_2 laser produced Sn plasmas. We use a novel pulse shortening technique to vary the CO_2 pulse duration from 5 - 50 ns, by ablating highly reflective metal targets. These shortened pulses are then incident on two Sn target types; bulk solid Sn and a pre-formed Sn plasma. We have investigated the effect of changing the CO_2 gas mixture and power density on the in-band emission centred on 13.5 nm. We present our findings and compare with CE from plasmas formed using the original long CO_2 pulse.

[1] Y. Tao, M. S. Tillack, S. S. Harilal, K. L. Sequoia, and F. Najmabadi: "Investigation of the interaction of a laser pulse with a preformed Gaussian Sn plume for an extreme ultraviolet lithography source". *J. Appl. Phys.*, **101**, 023305 (2007)
[2] J. White, P. Dunne, P. Hayden, F. O'Reilly, and G. O'Sullivan: "Optimizing 13.5 nm laser-produced tin plasma emission as a function of laser wavelength". *Appl. Phys. Lett.*, **90**, 181502 (2007)
[3] N. Hurst and S. S. Harilal: "Pulse shaping of transversely excited atmospheric CO_2 laser using a simple plasma shutter". *Rev. Sci. Instrum.*, **80**, 035101 (2009)
[4] S. S. Harilal, T. Sizyuk, V. Sizyuk, and A. Hassanein: "Efficient laser-produced plasma extreme ultraviolet sources using grooved Sn targets". *Appl. Phys. Lett.*, **96**, 111503 (2010)

P21

EUVL Flare Modeling with an Improved Accuracy for Feasibility Study of Sub-22nm HP Node

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It is needed to drive for next-generation lithography, because 193nm ArF lithography has physical limit of resolution. Even if current ArF double patterning technology is capable of reducing feature size smaller, it has many difficulties in implementing process flow and having competitive price. Therefore, extreme ultraviolet lithography (EUVL) has been intensively studied and developed for many years. EUVL pre-production tool is scheduled to be shipped to industrial semiconductor manufacturers in 2011 and many results and discussion of this year will be important in considering EUVL insertion timing

Flare is the total integrated light scattering at wafer level, which is generated from EUV optics including reflective EUVL mask. Flare affects critical dimension of unwanted areas across the exposure field. In this sense, it is required to predict accurate flare map for minimizing flare effect on CD uniformity.

Computationally, Flare is defined as a convolution of the flare point spread function (FPSF) with the clear-field mask reflection factor. FPSF was obtained from Kirk flare experiments with Alpha Demo Tool and in-house tool of which algorithm is based on multi-grid strategy, is used in flare modeling simulation. In order to reduce maximum flare error, we adopt proper sampling technique according to each FPSF of EUVL tool and effective reflection factors calculated by the optical property simulation software, TFCalc. Also, mask shadowing phenomenon was considered in flare calculation due to decreasing scattering area of clear-field mask where point sources of scattered light reach.

In this paper, we will show accurate flare modeling in EUVL, which is suitable for sub-22nm hp node. Additionally, we investigated the possibility of mask e-beam writing correction method for flare compensation under upcoming advanced optics.

P22

Comprehensive Simulation and Experimental Studies of EUV Lithography Source Issues

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Efficient extreme ultraviolet lithography (EUVL) sources are key requirement to advance the next generation nanolithography computer chips. Particularly efficient laser/target systems are essential for the realization of high volume manufacturing in extreme ultraviolet lithography (EUVL). Solid-state Nd:YAG asers usually have lower efficiency and source suppliers are alternatively investigating the use of high power CO2 laser systems. However, CO2 laser-produced plasmas (LPP) have specific characteristics and features that should be taken into account when considering them as the light source for EUVL. The analysis of recent experimental and theoretical work showed significant differences in the properties of plasma plumes produced by CO2 and the Nd:YAG lasers including EUV radiation emission, source formation, debris generation, and conversion efficiency. The much higher reflectivity of CO2 laser from liquid, vapor, and plasma of a tin target will result in the production of optically thinner plumes with higher velocity and in a better formation of plasma properties (temperature and density values) towards more efficient EUV source. However, the spikes in the temporal profiles of current CO2 laser will additionally affect the properties of the produced plasma. Optimization of target heating using pre-pulses or ablating low-density and nanoporous tin oxide can further improve LLP sources by creating more efficient plasma plumes and as a result increasing conversion efficiency (CE), the most important parameter for EUV sources. Another important challenge in developing LPP devices is to decrease fast ions and target debris to protect the optical collection system and increase its lifetime.

We continued to advance our unique combination of state-of-the art experimental facilities (CMUXE Laboratory) and advanced computer simulation (HEIGHTS) package for studying and optimizing various lasers, discharge produced plasmas (DPP), and target parameters as well as the optical collection system regarding EUV lithography. In this work, detailed characteristics of plasmas produced by CO2 and Nd:YAG lasers were analyzed and compared both experimentally and theoretically for optimizing EUV from LPP sources. The details of lower overheating of plasma produced by CO2 laser are given with time and explain how to utilize the high reflectivity of plasmas produced by such lasers in different target geometries to significantly enhance the CE of EUV radiation. We also studied the combined effects of prepulsing with various parameters and different target geometries on EUV conversion efficiency and on energetic ions production.

P23

Cleaning of Capped Multi-Layer Samples and Cleaning with Hydrogen using the Evactron® De-Contaminator

Christopher G. Morgan and Ronald Vane

XEI Scientific, Inc., Redwood City, CA, USA

Carbon contamination on extreme ultraviolet (EUV) optics reduces their reflectivity. Using Evactron® De-Contaminator downstream plasma cleaner with room air has been shown to be effective in removing carbon contamination from EUV optics. Radicals created by the Evactron process ash carbon contamination; the products are CO_2, CO, and H_2O.

Further studies of the effect cleaning multilayer blanks capped with either silicon or ruthenium by the Evactron system are presented. Room air and argon/oxygen mixtures are used as the cleaning gas. EUV reflectivity of the blanks and surface roughness are measured post cleaning to determine if the cleaning process is both effective and not harmful. Preliminary data shows that the oxygen mixtures are very effective at removing PMMA resist from a silicon wafer.

Additionally the use of hydrogen gas with the Evactron De-Contaminator is explored. Optical emission spectra of the plasma show that hydrogen radicals are created by the Evactron system. Cleaning effectiveness can be determined by using quartz crystal microbalances. The hydrogen atoms remove carbon contamination with maximum cleaning occurring at 100 mTorr chamber pressure. Rates around 1 nm per minute have been measured when the Evactron system is 15 cm from the quartz crystal microbalance.

Presenting Author

Christopher "Gabe" Morgan is currently the Product Manager for XEI Scientific, Inc. In 1991 he received his B.S. in Chemistry at Humboldt State University, and in 1997 he received his Ph.D. in Physical Chemistry at the University of California, Santa Barbara. His thesis topic was gas phase photodissociation chemistry. He has worked on atmospheric chemistry modeling at the Geological and Planetary Sciences Department at the California Institute from 1997-2002. He also worked on experimental atmospheric chemistry at SRI International from 2002-2004. From 2004-2007 he held analytical chemistry positions in various industries, and he started as Applications Scientist at XEI Scientific, Inc. in 2007.

P24

Developing Reflective Multilayer Coatings, an Enabling Component of Extreme Ultraviolet Lithography and Beyond

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EUV lithography requires, because of the wavelength of 13.5 nm, all reflective optics which can be realized by using multilayer Bragg reflectors for normal incidence. The research required to develop this class of optics is ongoing for several decades already but experienced an enormous boost from the extremely stringent requirements of EUV Lithography.

In this presentation we will discuss the path from fundamental research on the deposition of layers of a few nm thickness only towards a fully developed process, matured to deposit optics for prototype lithography machines. Topics like multilayer deposition, smoothing of interfaces, thermal stability, interface engineering, multilayer induced stress, and lateral uniformity will be discussed and examples of multilayer coated optics that fulfil the extremely tight specifications of EUV lithography machines will be discussed.

Yet, while the first EUV litho tools are being shipped to semiconductor manufacturers, research on multilayers for an even shorter wavelength of 6.x nm already takes place. This means other multilayer materials and, because of its increasing importance, even more focus on issues like smooth layer growth and prevention of intermixing.

Presenting Author

Eric Louis is a senior scientist at FOM Rijnhuizen (the Netherlands) where he is involved in research and development of soft X-ray and EUV multilayer reflective coatings since 1992. He worked on multilayers for several applications such as space research and synchrotron beam lines, but focused his research primarily on multilayers for EUV lithography. As leader of the group 'Advanced applications of XUV Optics', Eric Louis has been responsible for research, development and coating of various optics for EUV lithography. The extensive know how developed for this application is the basis for the development of multilayer coated optics for XUV and soft X-ray free electron lasers.

P25

Status of Multilayer Coatings for EUV Lithography

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Multilayer coating is a key element of EUVL optics. One can subdivide the EUVL optics into three categories – imaging optics, projection optics and collector optics. The first two are based on multilayers and the latest one contains multilayer coating if LPP sources are used and may comprise a single layer grazing incidence optics with DPP sources. Over more than 20 years of development performance of the multilayers was substantially improved in terms of peak reflectivity, wavelength accuracy, thermal and environmental stability. EUVL is approaching its first HVM phase and the multilayer deposition technology is getting ready to support it. This paper reviews a current status of the multilayer optics manufacturing. We present companies and groups involved in the multilayer production, requirements to the coatings, multilayer designs, imperfections, stability and accuracy. Emphasis will be given to remaining tasks to accomplish for HVM.

Presenting Author

Yuriy Platonov received MS degree in physics in 1977 from Moscow State University and PhD degree from Nizhny Novgorod State University in 1989. From 1978 to 1991 he worked at the Institute of Applied Physics of Russian Academy of Sciences (RAS) and his activities were focused on laser produced plasma diagnostics, pulsed laser deposition technology and multilayer X-ray optics. From 1991 to 1995 he ran the X-ray Optics Laboratory at the Institute for Physics of Microstructures of RAS. Since 1995 he is Director, Coatings and Senior Science Adviser at Rigaku Innovative Technologies, formerly Osmic. His field of scientific interests includes physics of artificial thin film structures, design and deposition of x-ray multilayer optical elements, X-ray analytical instrumentation, and multilayer neutron optics.

P26

Progress in modelling of high intensity radiation plasma sources

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M.B. Markov[c], S.V. Parot'kin[c]

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The phenomena in high power plasma light sources cover diverse disciplines, from plasma physics to atomic physics, from radiation transport to quantum mechanics, from magnetohydrodynamics to fast particle acceleration. Modelling tools and techniques that can describe the complete process from plasma formation to radiation and to formation of energetic particles, are lacking. The 2-D computational code Z* and its commercially available version Z*BME were designed at EPPRA to model multicharged ion plasmas in experimental and industrial facilities using a radiative magnetohydrodynamics (RMHD) approach. However, 3D plasma dynamics in electromagnetic field, more advanced atomic physics models and the need for spectral and angle-resolved 3-D analysis of radiation and fast particle emission are missing in the original code developed. The international collaborative project FIRE in the frames of FP7 IAPP aims to bridge this gap. The code Z* is upgraded to include recent advances in atomic physics and evolved into a hybrid 3-D code to address key issues in laboratory and industrial plasmas. Complex radiation understanding in unresolved transition arrays and non-stationary ionization in mutlicharged ions is combined. The radiation plasma dynamics, the spectral effects of self-absorption in laser-produced plasma and discharge-produced plasma, and resulting conversion efficiencies are considered. The generation of fast electrons, ions and neutrals is discussed. Conditions for the enhanced radiance of highly ionized plasma in the presence of fast electrons are evaluated. The innovative multiphysics code created is used to model high energy density plasma, to design powerfull radiation sources for the EUV lithographic industry and to deliver the requisite brightness and power for different applications.

Presenting Author

Dr. Sergey V. Zakharov graduated from the Moscow Physical-Technical Institute. He received the doctor degree in physical-mathematical sciences from Kurchatov Institute of Atomic Energy, Moscow, Russia, in 1984. He joined Troitsk Institute of Innovation and Fusion Research (TRINITI), Russia, in 1981, where he is currently Head of the theoretical laboratory. His works concern plasma turbulence theory, nonlinear waves, charged particle beams, radiation-magnetohydrodynamics and non-equilibrium plasma theory in HEDP and ICF. For works on interaction of high power electron beams with dense gas he was rewarded the State Prize for young scientists and engineers in 1987. For researches on high energy density physics and radiating multicharged ion plasma he was rewarded the Great Government Reward in 1997. Since 1999 he joined EPPRA SAS, France, as a Principal Scientist. He works on the theory of non-equilibrium heavy-ion plasmas and modeling of discharge and laser produced plasma radiation sources. Under his leadership the radiation-magnetohydrodynamic codes ZETA and Z* were created and are being developed.

P27

High brightness EUV & soft-X-ray MPP discharge source system development

Peter Choi[ab], Sergey V. Zakharov[ab+], Raul Aliaga-Rossel[a], Aldrice Bakouboula[a], Otman Benali[ab], Philippe Bove[a], Michèle Cau[a], Grainne Duffy[a], Blair Lebert[b], Ouassima Sarroukh[b], Clement Zaepffel[a], Vasily S. Zakharov[b]

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The roll out of EUV lithography, including the associated tools for actinic mask inspections, requires reliable and powerful EUV radiation sources. The radiation is in the 13.5nm region, originating typically from a high Z high energy density plasma at a temperature of 20-40eV, Unlike most laboratory sources, these industrial high energy density plasma sources operates in 1-20 kHz repetition rate in a continuous mode, and are created in laser-produced plasmas or in discharge produced plasmas. High brightness EUV & soft X-ray sources have wide perspectives in instrumentation and applications in metrology. NANO-UV has developed a unique EUV/soft X-ray source, the CYCLOPS™, based on a hollow cathode triggered micro-plasma pulsed (MPP) discharge, incorporating an intrinsic plasma structure to provide photon collection and delivery. We report on the light source development, including the extensive numerical modelling which provided the basic parameters required for high power or high irradiance operating regimes. Without using external physical optics, a peak irradiance exceeding 10^{18} ph/cm^2/s, in a 3 nm bandwidth around 13.5nm, has been recorded at a distance 74 cm downstream from the source, which was operating at 1 kHz in a He:N_2:Xe gas admixture at up to 0.5J per pulse operation. A Sn-alloy cathode material has enhanced the in-band output. The power delivered in a sub-cm size spot is greater than 20W in 3nm band, with a typical étendue below 10^{-2} mm^2•sr. The low etendue of the source opens up the possibility to increase the power and brightness of the radiation source through spatial (static) and/or temporal (dynamic) multiplexing of such modulars. A multiplex of 12 units, the HYDRA™ -12P has been constructed to study the interaction between multiple sources and to evaluate functional aspects of a multiplexed system. This source has the potential of reaching 240W (within 3 nm EUV band) at an intermediate point at some distance away from the source, the so called intermediate focus (IF). The general characteristics of the CYCLOPS™ sources and the HYDRA™ -12P device will be presented.

Presenting Author

Dr. Sergey V. Zakharov graduated from the Moscow Physical-Technical Institute. He received the doctor degree in physical-mathematical sciences from Kurchatov Institute of Atomic Energy, Moscow, Russia, in 1984. He joined Troitsk Institute of Innovation and Fusion Research (TRINITI), Russia, in 1981, where he is currently Head of the theoretical laboratory. His works concern plasma turbulence theory, nonlinear waves, charged particle beams, radiation-magnetohydrodynamics and non-equilibrium plasma theory in HEDP and ICF. For works on interaction of high power electron beams with dense gas he was rewarded the State Prize for young scientists and engineers in 1987. For researches on high energy density physics and radiating multicharged ion plasma he was rewarded the Great Government Reward in 1997. Since 1999 he joined EPPRA SAS, France, as a Principal Scientist. He works on the theory of non-equilibrium heavy-ion plasmas and modeling of discharge and laser produced plasma radiation sources. Under his leadership the radiation-magnetohydrodynamic codes ZETA and Z* were created and are being developed.

P28

Gas-based Spectral Filter for Mitigating 10.6 μm Radiation in CO_2 Laser Produced Plasma Extreme Ultraviolet Sources

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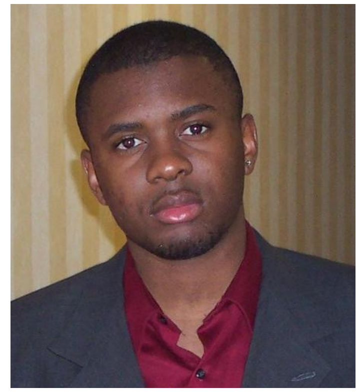
Next generation high volume manufacturing lithography tools will likely use CO_2 laser produced plasma sources to generate extreme ultraviolet (EUV) radiation needed for resist exposures. Existing mitigation techniques for out-of-band radiation from these sources result in reduced EUV (13.5 nm) transmission to the resist plane which decreases desired throughput. New methods to suppress the 10.6 μm radiation, which dominates the out-of-band spectrum at the intermediate focus (IF), need to be examined. A spectral filter design that uses an infrared absorbing gas to target the mitigation of 10.6 μm in these EUV tools may provide another alternative to suppress the unwanted radiation. This work explores infrared absorption of gases at 10.6 μm while focusing on gaseous sulfur hexafluoride (SF_6) whose υ_3 infrared active mode is vibrationally excited by 10.6 μm photons. A compact tunable CO_2 laser is used to measure the room temperature, low fluence absorption of SF_6 in the range of 10.53-10.65 μm. In addition, the EUV transmission of SF_6 as a function of pressure is estimated based on the absorption cross section measured for wavelengths between 11-17 nm. Design considerations such as the EUV transmission *vs.* infrared absorption tradeoff are discussed.

Presenting Author



Chimaobi Mbanaso is a doctoral graduate student at the College of Nanoscale Science and Engineering (CNSE) at the State University of New York, University at Albany (SUNY Albany). He obtained his bachelor's degree from Howard University in Washington, DC in 2006 and his Master's degree in Nanoengineering from SUNY Albany in 2009. His research interests include out-of-band radiation related challenges in extreme ultraviolet (EUV) lithography and outgassing from EUV resists.

P29

Mass Spectrometer Characterization of Reactions in Photoresists Exposed to Extreme Ultraviolet Radiation

Chimaobi Mbanaso, Seth Kruger, Craig Higgins, Yashdeep Khopkar, Alin Antohe, Brian Cardineau, Gregory Denbeaux

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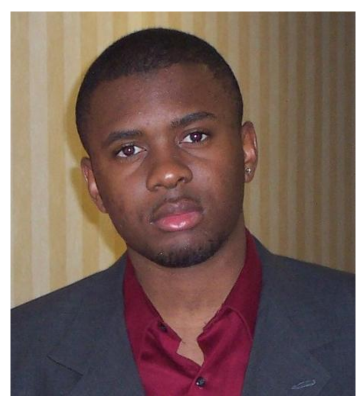
The development of resists that meet the requirements for resolution, line edge roughness and sensitivity remains one of the challenges for extreme ultraviolet (EUV) lithography. Two important processes that contribute to the lithographic performance of EUV resists involve the efficient decomposition of a photoacid generator (PAG) to yield a catalytic acid and the subsequent deprotection of the polymer in the resist film. We investigate these processes by monitoring the trends produced by specific masses outgassing from resists following EUV exposure and present our initial results. The resists tested are based on ESCAP polymer and either bis(4-*tert*-butylphenyl)iodonium perfluoro-1-butanesulfonate or bis(4-*tert*-butylphenyl)iodonium triflate. The components originating from the PAG were monitored at various EUV exposure doses while the deprotection of the polymer was monitored by baking the resist in vacuum and detecting the cleaved by-product from the polymer with an Extrel quadruple mass spectrometer.

Presenting Author

Chimaobi Mbanaso is a doctoral graduate student at the College of Nanoscale Science and Engineering (CNSE) at the State University of New York, University at Albany (SUNY Albany). He obtained his bachelor’s degree from Howard University in Washington, DC in 2006 and his Master’s degree in Nanoengineering from SUNY Albany in 2009. His research interests include out-of-band radiation related challenges in extreme ultraviolet (EUV) lithography and outgassing from EUV resists.



P30

Design of high brightness laser-Compton Light Source for EUV Lithography Research in Shorter Wavelength Region"

Kazuyuki Sakaue, Masakazu Washio, Akira Endo

Research Institute of Science and Engineering, Waseda University, Tokyo, Japan

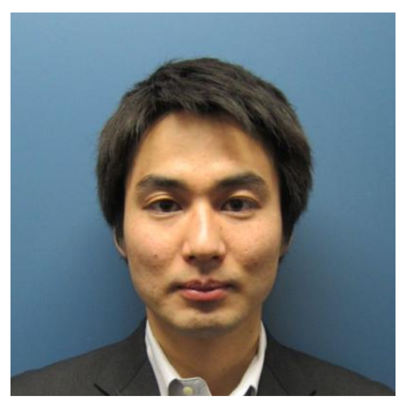
Recent progresses of high average power pulsed CO2 lasers and intense electron beam make it possible to produce milli-watt class EUV light source with 1000W/mm2Sr brightness via laser-Compton scattering.

Laser-Compton X-ray beam has a good directivity and angularly distributed quas i-monochromatic spectrum, and the wavelength of the X-ray is short enough even the electron beam energy is several MeVs, because the undulation period of electron, i.e. the laser wavelength, is much shorter than that of magnetic undulators.

These properties meet requirements in the course of 6.7nm lithography research. Our design consists of CO2 laser enhancement cavity and cw electron accelerator. This light source shall achieve more than 1mW with 1000W/mm2Sr brightness. We have already achieved more than 500enhancement with 1um pulsed laser in super-cavity and produced hard X-ray through the laser-Compton scattering with 40MeV electron beam. Then, the design requires demonstration of CO2 super-cavity and pulse compress ion of CO2 laser.

We have at first started a study of enhancement cavity at CO2 laser wavelength. The designs of our high brightness EUV source, the progresses of R&D and future vision of our design will be presented.

Presenting Author



Kazuyuki Sakaue is Assistant Professor of Applied physics department at Waseda University. He received a Ph. D degree in Accelerator Science from Waseda University. He has been active in the area of electron accelerators and laser-beam interactions for over 8 years. His current research involves study of high quality electron beam generation and the laser enhancement super-cavity system for upgrading the laser-beam interactions.

P31

LER metrology: can we trust the numbers

Patrick P. Naulleau

Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA

Presenting Author

Dr. Patrick P. Naulleau has been involved in EUV lithography since 1997 when he joined Lawrence Berkeley National Laboratory (LBNL) to work in the area of actinic interferometric alignment. Since 2001 he has lead LBNL's EUV Patterning project starting with the 0.1-NA ETS optics and now the 0.3-NA MET optic. He is internationally recognized for leading EUV patterning studies and his contributions to EUV System designs. He is the lead author of chapter on EUV Patterning in the book EUV Lithography.

P32

Surface Metrology and Polishing Techniques for Current and Future-generation EUVL Optics

Regina Soufli

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It is well known that the resolution, flare, throughput and other crucial features of any EUVL system depend largely on the figure, mid- and high-spatial frequency roughness of its constituent optical substrates. It has also been established that the lowest achievable figure/roughness from any figuring/polishing method is ultimately limited by the accuracy and precision of the surface metrology employed. This review presentation addresses the current state-of-the-art and future challenges in polishing and surface metrology techniques for EUVL optics and for other applications in the EUV/x-ray region. The figure and roughness specifications for EUVL optics will be reviewed. Experimental results for the roughness (obtained via Atomic Force Microscopy and optical profilometry) and for the figure (obtained via full-aperture interferometry) will be shown from a variety of optical substrates such as glass, silicon and silicon carbide. The potential and limitations of these materials as EUVL camera or collector substrates will be presented. Examples of the impact of figure and roughness errors in the experimental performance of EUV systems, and a cross-validation of surface metrology with EUV reflectance and scattering measurements will be given. Optics requirements and challenges towards recently proposed photolithography at 6.x nm illumination wavelengths will also be discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Presenting Author

Regina Soufli received her Ph.D. in Electrical Engineering from the University of California, Berkeley, and was staff scientist at the Harvard-Smithsonian Center for Astrophysics working for NASA's Chandra X-ray Observatory. At Lawrence Livermore National Lab she has been principal investigator on EUV/x-ray optics programs for EUV lithography, solar physics, synchrotron and free-electron lasers, and high-energy physics. She has recently been working on x-ray optics for the Linac Coherent Light Source (LCLS), the world's first x-ray free electron laser, and on EUV multilayer optics for NASA/NOAA's space weather satellites and NASA's Solar Dynamics Observatory. Her interests are in EUV/x-ray interactions with matter, surface science, thin films, roughness and scattering. She is author of over 60 publications and a book chapter, and has received two "R&D 100" awards.

P33

EUVL R&D Status – Korea

Jinho Ahn

Hanynag University, Korea

Overview of EUVL R&D Status in Korea.

Presenting Author

Jinho Ahn received his B.S. (1986) and M.S. (1988) degrees from Seoul National University, and Ph.D. (1992) degree from the University of Texas at Austin all in MSE department. He worked for NEC, Japan (1993 – 1995), and joined Hanyang University in 1995 as a professor at MSE department. He also works as a director of New Growth Engine Semiconductor Research Center of the Ministry of Commerce, Industry and Energy. Currently, he is a leader of national projects for "EUV lithography technology" and "Stepper development for displays."

P34

1st/2nd Generation Laser-Produced Plasma light source system for HVM EUV lithography

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Tsukasa Hori, Tatsuya Yanagida, Hitoshi Nagano, Takayuki Yabu, Shinji Nagai, Georg Soumagne,Akihiko Kurosu, Krzysztof M. Nowak, Takashi Suganuma, Masato Moriya,
Kouji Kakizaki, Akira Sumitani,Hidenobu Kameda*1, Hiroaki Nakarai*1, Junichi fujimoto *1

EUVA/Komatsu (Japan): Hiratsuka, Kanagawa, Japan
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In this paper we update performance status of the 1st generation system. We have improved the system further, maximum burst power is 104W (100kHz, 1 mJ EUV power @ intermediate focus), laser-EUV conversion efficiency is 2.5%. Also continuous operation time is so far up to 8 hours with 5% duty cycle is achieved. We have investigated EUV plasma creation scheme by small experimental device which is facilitated 10Hz operation (maximum). We have proposed double pulse method to create LPP plasma efficiently. This moment we found out 3.3% conversion efficiency operation condition.

Based on the engineering data of ETS and small experimental device, now we are developing 2nd generation HVM source; GL200E. The device consists of the original concepts (1) CO_2 laser driven Sn plasma, (2) Hybrid CO_2 laser system that is combination of high speed (>100kHz) short pulse oscillator and industrial cw-CO_2, (3) Magnetic mitigation, and (4) Double pulse EUV plasma creation. The preliminary system operation data will be introduced in this paper.

P35

EUVL R&D Status- US

Greg Denbeaux

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Overview of EUVL R&D Status in US.

Presenting Author

Professor Gregory Denbeaux's research focuses on high-resolution microscopy for lithography and magnetic materials, as well as high-resolution optical techniques. His research on magnetic materials focuses on nanometer-scale magnetism and magnetic recording. Denbeaux, who also serves as a staff scientist at the Center for X-Ray Optics at Lawrence Berkeley National Laboratory, received his bachelor's degree in physics from Wesleyan University and master's and doctorate from Duke University.

P36

Feasibility Study of Chemically Amplified Resists for Short Wavelength Extreme Ultraviolet Lithography

Takahiro Kozawa[1] and Andreas Erdmann[2]

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With the realization of 13.5 nm extreme ultraviolet (EUV) lithography, further reduction in wavelength has attracted much attention. In this study, the optical images, sensitization processes, and chemical reactions in a chemically amplified resist were calculated to estimate the performance of the resist upon exposure to 6.67 nm EUV radiation. It was found that the reduction in wavelength improves the lithographic image quality even if the secondary electrons generated by high-energy photons are taken into account. One of the keys to the realization of 6.67 nm lithography is the development of high-absorption resists.

Presenting Author

Takahiro Kozawa is an associate professor of the Institute of Scientific and Industrial Research (ISIR), Osaka University. He received his BS and MS degrees in nuclear engineering from the University of Tokyo, and PhD degree in chemical engineering from Osaka University in 1990, 1992, and 2003, respectively. His work is mainly focused on beam-material interaction and beam-induced reactions in resist materials.

P37

Recent Progress in Nano-space Radiation Chemistry Research on Sensitivity Enhancements of EUV Resists

Seiichi Tagawa[1,2]

[1] *The Institute of Scientific and Industrial Research, Osaka University,*
[2] *Japan Science and Technology Agency, CREST, c/o Osaka University, Ibaraki, Osaka, Japan*

The increasing density of semiconductor devices has required the development of high resolution exposure techniques. The miniaturization of feature sizes has been achieved mainly by shortening the wavelength of exposure tools. The shortening of wavelength means the increase in the photon energy of exposure tools such as extreme ultraviolet (EUV, 13.5 nm) lithography, where ionization is a main process. Recently, high sensitive resists are required for EUV. Nowadays chemically amplified resist (CAR) is only one high sensitive resist and the situation will not change in the near future. The present paper reviews recent progress in nano-space radiation chemistry research on sensitivity enhancements of chemically amplified EUV resists, especially pulse radiolysis research on the detaled mechanisms of acid generation of chemically amplified EUV resists such as fluorinated polymer resists, acid amplified resists, and resists at 6.x nm.

Presenting Author

Prof. Seiichi Tagawa is currently the Director of Beam Application Frontier Laboratory at the Institute of Scientific and Industrial Research, Osaka University. He is also the Head of Nanofabrication Function, Handai-Functional Nanofoundry, Osaka University and the Distinguished Professor/ Emeritus Professor of Osaka University. He is also a Visiting professor and visiting senior researcher, Waseda University. He received his Ph.D. in Nuclear Engineering, University of Tokyo in 1973

P38

EQ-10 Electrodeless Z-Pinch EUV Source for Metrology Applications

Deborah Gustafson, Stephen F. Horne, Matthew M. Besen, Donald K. Smith, Matthew J. Partlow, Paul A. Blackborow

Energetiq Technology, Inc., Woburn, MA, USA

With EUV Lithography systems shipping the requirements for highly reliable EUV sources for mask inspection and resist outgassing are increasing. The sources needed for metrology applications are very different than that needed for lithography, brightness is the key. Suppliers for HVM EUV sources have all resources working on high power and will not focus on the smaller market for metrology.

Energetiq Technology has been shipping the EQ-10 Electrodeless Z-pinch™ light source since 1995. The source is currently being used for metrology, mask inspection, and resist development. These applications require especially stable performance in both output power and plasma size and position.

Over the last 6 years Energetiq has made many source modifications which have included better thermal management to increase our brightness and power of the source. We now have introduced a new source that will meet requirements of some of the mask metrology first generation tools and this source will be reviewed.

Presenting Author

Debbie Gustafson is an industry veteran for over 20 years and has held various management positions in technical Sales and Marketing in the Semiconductor Equipment Industry. Her focus has been on component and subsystem equipment and service and has worked at ASTeX, Mykrolis and Helix. Ms. Gustafson's is a senior manager at Energetiq Technology, Inc. in Woburn, Massachusetts as their Vice President of Sales and Service. Her responsibility also includes marketing and the management of manufacturing and finance. Currently Ms. Gustafson is the chairperson of the SEMI New England Committee. She holds a BS in Mechanical Engineering and an MBA in Management from Bentley College.

P39

Doing Business in Maui

Kimberly Haueisen, Mark Ausbeck*

Maui Economic Development Board (MEDB), Inc., Kihei, Hawaii, USA
* High Tech Development Corporation (HTDC), Kihei, Hawaii, USA

Presenting Author

Kimberly A. Haueisen serves as a Program Director at the Maui Economic Development Board (MEDB), Inc. She provides support for new and existing businesses, as well as the development of innovative programs to ensure the islands' continued economic strength. MEDB's mission is to provide leadership and vision in our community for the responsible design and development of a strong, sustainable, and diversified economy for Maui County. The vision is a future in which abundant opportunities for rewarding employment are met by a qualified, resident workforce in Maui County, a community which honors its cultural heritage and natural environment. Kimberly graduated with a Bachelor of Arts degree from Eastern Connecticut State University in Psychology and Computer Science. Kimberly completed graduate course work in Training and Development from Pennsylvania State University, and International Business at the University of Phoenix. Her background includes directing application development in both federal and state agencies, conducting software development and system integration training, providing classroom and hands-on instruction, and facilitating the implementation of federally mandated computer systems in multiple states.

Mark Ausbeck is a Project Manager for HTDC-MEP. Mark has over 15 years of experience in manufacturing. For 10 years Mark served as Process and Systems Engineer for U.S. Pipe & Foundry, Co. in Birmingham, AL. His experience there included automation, data analysis, process improvement. Mark then joined Alabama Technology Network, the Alabama NIST-MEP affiliate, as a Project Manager. His work there was concentrated in the areas of Lean Manufacturing, Energy Efficiency, and Environmental Health and Safety. Mark holds a B.S. degree in Electrical Engineering from Georgia Tech and an MBA from the University of Alabama at Birmingham.

EUV

Litho, Inc.